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THREE DIMENSIONAL VCR

Bosi Wang

Texas Accelerator Center

2319 Timberloch Place Bay H

The Woodlands, Texas 77380

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Abstract

The existing method of vane coupling rings (VCR) for field stabilization in 4 vane RFQ cavity has several disadvantages. One of them is that it cannot stabilize the field distribution in the longitudinal direction of the cavity. The other is the maximal filed perturbation and the disctrete capacitance loading of VCR along the Z-axis. In order to overcome these disadvantages in this paper a new method of field stabilization in RFQ cavity is proposed which is called 3-dimensional VCR (3-D VCR). In contrast with the VCR the 3-D VCR can simultaneously stabilize the field distribution in both of azimuthal and longitudinal directions and it has less field perturbation and more uniformly capacitance loading along the z-axis of the RFQ cavity than that of the existing VCR method.

CONTENTS

1. INTRODUCTION

The field stabilization in RFQ linac is important for both of the field flatness adjustment and of reliable operation of RFQ linac. Recently there are mainly two methods for field stabilization in RFQ. One is the vane coupling rings (VCR)[1]. The other is the resonant loop coupling (RLC)[2]. Both methods are successfully used in several RFQ linacs.

From the point of view of periodic system both of the RFQ structures with VCR and RLC field stabilization devices are equivalent to an 8-cell circular periodic system.[3] When the structures are working in the RFQ quadrupole mode it is corresponding to the $\pi/2$ mode of the 8-cell circular periodic system in azimuthal direction. The group velocity of electromagnetic energy flow for quadrupole mode in transverse direction is large. But there is no longitudinal electromagnetic energy flow for quadrupole mode in the RFQ cavity.

The improvement of field flatness in longitudinal direction in the RFQ cavity with VCR or RLC is only because the interference of the dipole mode is removed away.

Of course in the static case (low rf power without beam loading) the longitudinal field flatness can be tuned by the end gap piston tuners, side wall piston tuners and shaping of the vane end form. But in the dynamic case (high rf power with beam loading) the longitudinal field flatness can be distorted by rf heating and beam loading.

In order to overcome these disadvantages of the RFQ structure with the existing VCR (Here after we'll call it 2-dimensional VCR because in this structure the plane of vane coupling ring is perpendicular to the axis of the RFQ cavity and it can be specified by two polar coordinates r and ϕ only) a new field stabilization device for RFQ linac is proposed which we'll call 3-dimensional VCR (it is because the plane of coupling ring in this case is specified by all 3 polar coordinates r, ϕ, z.

2. THE ADVANTAGES AND DISADVANTAGES OF 2-DIMENSIONAL VCR (2-D VCR)

Up till now the 2-D VCR is used in many RFQ linacs successfully. In many labs people have already had a lot of experiences in manufacture, assembly and operation of it. Actually the mechanical structure of 2-D VCR is very simple. These are the advantages of the 2-D VCR.

The disadvantages of the 2-D VCR are the following. As it was mentioned in the introduction that the RFQ cavity with 2-D VCR is equivalent to an 8-cell circular periodic system[3] in the transverse plane of the RFQ structure and the quadrupole mode of RFQ is corresponding to the $\pi/2$ mode of the 8-cell circular periodic system. Therefore in the RFQ structure with 2-D VCR the quadrupole field distribution in the longitudinal direction is not stabilized. The reason for this can be illustrated by the following physical picture. In the ideal case (absence of dipole
and π-2π-like modes
mode) there are no rf currents flowing along the coupling rings.

But in the non-ideal case (presence of dipole mode and TE-21n-like modes) there are rf currents flowing along the coupling rings. In this case because the plane of the vane coupling ring is perpendicular to the axis of the cavity the rf current flowing along the coupling ring only has azimuthal component I_ϕ which will produce around the conductor of coupling ring magnetic field shown in Fig. 1.

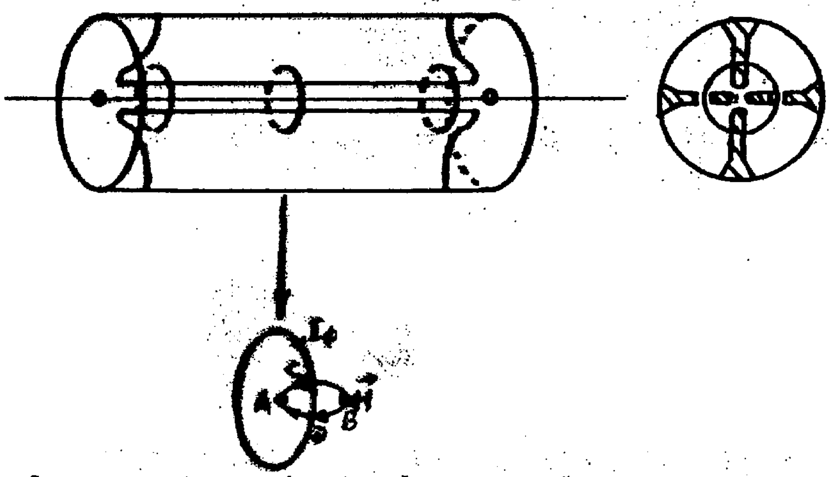
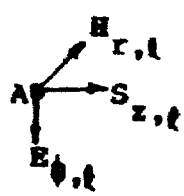


Fig. 1 The schematical picture of 2-D VCR showing the eletromagnetic energy flowing in both of the axial and radial directions.

At point A there are field components: $E_{\phi,\ell}$, $H_{r,\ell}$ the Poynting's vector

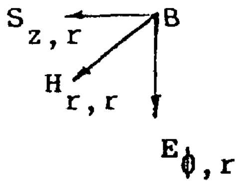
$$S_{z,\ell} = E_{\phi,\ell} \times H_{r,\ell}$$



from left to right

At point B there are field components: $E_{\phi,r}$, $H_{r,r}$, the Poynting's vector

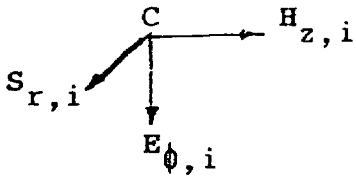
$S_{z,r} = E_{\phi,r} \times H_{r,r}$



from right to left

At point C there are field components: $E_{\phi,i}$, $H_{z,i}$, the Poynting's vector

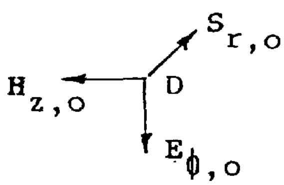
$S_{r,i} = E_{\phi,i} \times H_{z,i}$



out off axis

At point D there are field components: $E_{\phi,o}$, $H_{z,o}$ the Poynting's vector

$S_{r,o} = E_{\phi,o} \times H_{z,o}$



into axis

where $E_{\phi,l}$, $H_{r,l}$ and $S_{z,l}$ denote ϕ,r and z components of the corresponding quantities on the left side of the coupling ring; $E_{\phi,r}$, $H_{r,r}$ and $S_{z,r}$ denote ϕ,r and z components of the corresponding quantities on the right side of the coupling ring; $E_{\phi,i}$, $H_{z,i}$ and $S_{r,i}$ denote the ϕ, z and r components of the corresponding quantities inside the coupling ring; $E_{\phi,o}$, $H_{z,o}$ and $S_{r,o}$ denote the ϕ, z and r component of the corresponding quantities outside the coupling ring.

In Fig. 1 it can be seen that the two longitudinal electromagnetic energy flows $S_{z,\ell}$ (the Poynting vector from the left side of the coupling ring) and $S_{z,r}$ (the Poynting vector from the right side of the coupling ring) are canceled each other. This is because

$$E_{\phi,\ell} = E_{\phi,r} \tag{2.1}$$

$$H_{r,\ell} = -H_{r,r} \tag{2.2}$$

Therefore $S_{z,\ell} = -S_{z,r}$ (2.3)

Consequently the sum of longitudinal electromagnetic energy flows is zero

$$S_{zs} = S_{z,\ell} + S_{z,r} = 0 \tag{2.4}$$

On the other hand in the radial direction inside the coupling ring the azimuthal component of electric field larger than that outside the coupling ring, that is

$$E_{\phi,i} > E_{\phi,o} \tag{2.5}$$

and the axial component of magnetic field inside the coupling ring produced by the rf current flowing along the coupling ring is also larger than that outside coupling ring, that is

$$H_{z,i} > H_{z,o} \tag{2.6}$$

Therefore the Poynting vector in radial direction from inside coupling ring is larger than that from outside coupling ring, that is

$$S_{r,i} = E_{\phi,i} \times H_{z,i} \tag{2.7}$$

$$S_{r,o} = E_{\phi,o} \times H_{z,o} \tag{2.8}$$

though $S_{r,i}$ and $S_{r,o}$ are opposite in direction the net electromagnetic energy flow $S_{r,s}$ is not zero

$$S_{r,s} = S_{r,i} - S_{r,o} \neq 0 \tag{2.9}$$

From equations (2.4) and (2.9) it is obvious that in the RFQ cavity with 2-D VCR there is no longitudinal field stabilization. Actually 2-D VCR improves the longitudinal field distribution only in the meaning of increasing the mode separation between TE_{210} -like mode and TE_{110} -like mode. In this way the field components of TE_{110} -like mode less contribute to the longitudinal field distribution of the TE_{210} -like mode. But ~~for~~ in

(the case of presence of TE_{110}, TE_{21n} modes
~~TE_{210}~~-like mode there is no longitudinal electromagnetic energy flow.

There is another disadvantage of 2-D VCR. In the RFQ cavity with 2-D VCR the plane of the vane coupling ring is perpendicular to the axis of the cavity. Therefore the conductor of the vane coupling ring is parallel to the electric field line E_ϕ of RFQ cavity. So the local field disturbance by the 2-D VCR is maximum and the local capacitance loading is concentrated in the place where the plane of the coupling ring intersects the axis of the cavity. The total effect of these is to introduce additional longitudinal field unflattness.

3. The 3-D VCR

The basic idea of 3-D VCR is to change the way of connection of two opposite vanes by coupling rings in the RFQ cavity to produce the longitudinal electromagnetic energy flow. For this purpose the plane of the coupling ring is inclined to the axis of the cavity instead of perpendicular to the axis as in the case of the 2-D VCR. There are several ways to arrange the inclined coupling rings along the axis of the cavity. One of them is mono-inclined (see Fig. 2).

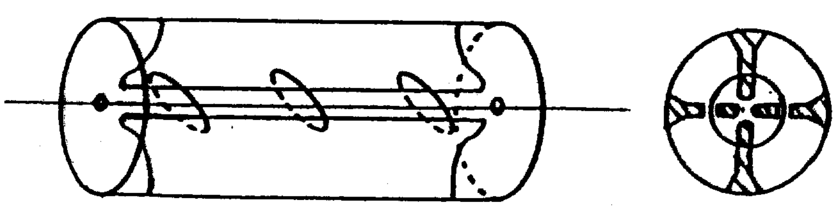


Fig. 2 One way of arrangement of vane coupling rings (mono-inclined)

The other way of arrangement of the vane coupling rings is alternate-inclined (see Fig. 3).

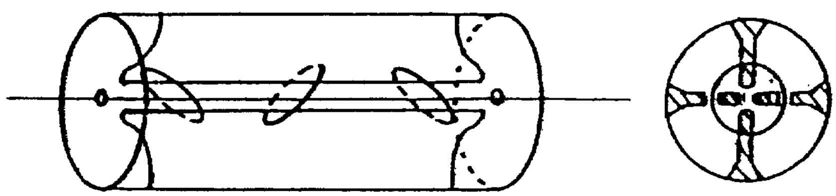
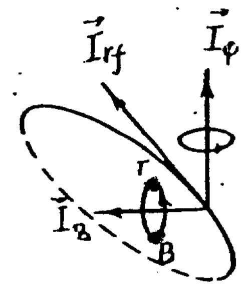
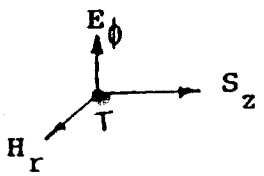


Fig. 3 The other possible way of arrangement of inclined coupling ring (alternate-inclined coupling rings)

In this case the z-components of rf currents on the adjacent coupling rings are opposite and it can be seen later the net longitudinal electromagnetic energy flow produced by H_r and E_ϕ will be zero. So we shall discuss the RFQ structure with mono-inclined vane coupling rings shown in Fig. 2. In Fig. 2 if one inclined coupling rings is enlarged in Fig. 4 in which the rf current flowinng along the vane coupling ring I_{rf} is decompounded ~~in~~ the azimuthal component I_ϕ and the axial component I_z.
into

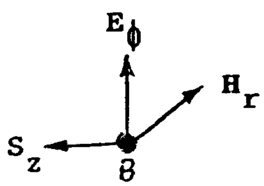


At point T there are field components $H_{r,t}$ and $E_{\phi,t}$ the Poynting vector $S_{z,t} = E_{\phi,t} \times H_{r,t}$



from left to right

At point B there are field components $H_{r,b}$ and $E_{\phi,b}$ the Poynting vector $S_{z,b} = E_{\phi,b} \times H_{r,b}$



from right to left

Fig. 4 The enlarged inclined coupling ring, rf current components and the longitudinal electromagnetic energy flows.

The effect of I_ϕ has already been discussed in Section 2 for the case of 2-D VCR. The effect of I_z will be discussed in details here. It is the essential of the 3-D VCR.

In Fig. 4 the point T is above the current component I_z, the electromagnetic energy flow $S_{z,t}$ at this point is going through the cross-section of above part of the cavity and the point B is under the I_z, the electromagnetic energy flow at this point $S_{z,b}$

is going through the cross-section of the low part of the cavity. Though the directions of $S_{z,t}$ and $S_{z,b}$ are opposite they do not meet each other. So the total effect of electromagnetic energy flow in longitudinal direction is the sum $|S_{z,s}|$ of $|S_{z,t}|$ and $|S_{z,b}|$

$$|S_{z,s}| = |S_{z,t}| + |S_{z,b}| \tag{3.1}$$

where

$$S_{z,t} = E_{\phi,t} \times H_{r,t} \tag{3.2}$$

$$S_{z,b} = E_{\phi,b} \times H_{r,b} \tag{3.3}$$

So in the RFQ structure with 3-D VCR when the structure is perturbed there exist both transverse and longitudinal electromagnetic energy flows which are important to balance the disturbed electromagnetic field flatness in both azimuthal and longitudinal directions.

The other advantage of the RFQ structure with 3-D VCR is the perturbation on the E_{ϕ} by the conductors of vane coupling rings is smaller and more uniformly distributed along z-axis than that in the case of 2-D VCR and the local capacitance loading along the z-axis is also more uniformly distributed than the discrete capacitance loading in the case of 2-D VCR. This is simple because the vane coupling rings are inclined to the axis of the RFQ cavity instead of that the vane coupling rings are perpendicular to the axis of the cavity as in the case of 2-D VCR.

4. Conclusion

According to the above analysis the following conclusion can be made:

- 2-D VCR can increase the mode separation between TE_{210} -like mode and TE_{110} -like mode. Therefore it can be used to reduced the contribution of the field components of TE_{110} -like mode to the field distribution of TE_{210} -like mode. It can stabilize the field distribution of TE_{210} -like mode in azimuthal direction. But it can not stabilize the field distribution of TE_{210} -like mode in longitudinal direction.

- The perturbation on the E_ϕ in RFQ cavity by 2-D VCR is maximum because the conductor of the coupling ring is parallel to the E_ϕ and the local capacitance loading of the vane coupling rings is discretely distributed along the z-axis of the cavity. This introduces an additional longitudinal unflattness of the field in the RFQ cavity.

- In contrast with the 2-D VCR in the RFQ cavity with 3-D VCR there exist simultaneously transverse electromagnetic energy flow and longitudinal electromagnetic energy flow. So it can simultaneously stabilize field distribution of TE_{210} -like mode in both azimuthal and longitudinal directions.

-Because the conductors of 3-D VCR are inclined to E_ϕ in the RFQ cavity the perturbation of E_ϕ by 3-D VCR is less and more uniformly distributed along z-axis than that in the case of 2-D VCR and the local capacitance loading along the z-axis is also more uniform than in the case of 2-D VCR.

- From the point of view of mechanical structure the 3-D VCR is evolved from the 2-D VCR. So in mechanical structure the 3-D VCR is as simple as 2-D VCR.

References

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(2) A. Schempp, Field Stabilization with Resonant Couplers, 1986 Linear Accelerator Conference Proceedings, P. 251, SLAC (1986).

(3) Bosi Wang, Theory of Circular Periodic System and RFQ Structure, Report of TAC, (1987).